Biomimetic principles in sustainable architecture design, using natural materials as straw, clay and mycelium

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Keywords : bionics, biomimetics, sustainability, environmental design, natural materials, straw, clay, mycelium, symbiotic relations;

I. Introduction

This study is part of my dissertation work, on topic "*Innovative methods of biomimetics and bionics in architecture and their transformations*". The aim of the report is to register, from biomimetic point of view, what is the place of the listed natural materials in the newly proposed unified paradigm of several models of sustainability in architecture. In the first part of the study I will examine some known concepts and then I will propose a scheme, depicting the combination, mutual suppletion and unification of the introduced models. In the second part of the report, a criterion for symbiotic behaviour in architecture will be proposed and then approbated by holistic exploration of chosen examples. Straw, clay and mycelium will be analized, on multiple levels - according the proposed criterion, in order to be evaluated not only as sustainable, but also as materials, possessing biomimetical potential.

II. Existing and proposed terminology, models and connection with sustainability in architecture.

It is important firstly a short introduction with the terms to be made – what is actually bionic/biomimetic design and how is it connected with architecture. Those are terms introduced in the middle of the 20th century and they are both inspired from principles, found in nature. Still, their meaning and definitions gradually and continuously undergo dynamic development in many scientific spheres. Thus, they branch out in more specified categorization such as "technical bionics", and "architectural bionics". One of the researchers in that field, Yuri Lebedev, writes in 1990, about the bionic/biomimetic principles in architecture and how the object of study there is mainly related to "functional and morphologic laws and principles, found in nature (living organisms), aiming to use them for improving of architectural solutions, forming of complex architectural and urban systems**, harmonizing the relations between architecture and the surrounding natural environment ."** [1]

Thus, **this definition shows the potential for applying biomimetic methods not only as a source of inspiration and solutions of technological and engineering(structural) problems, but in the greater scale** on the level of architecture-human-environment relations and behaviour types, and also explains the connection between biomimetics and the search for more "vivid" connection between architecture/design and its surroundings, development of eco-sustainable habitats, harmonizing with the social and technical progress of the cities. **This balance between nature and technology, between human built and natural environment, is also one of the main sustainability issues.**

And so numerous specialist in the "green" and "eco" movements for architectural sustainability have gradually elaborated and developed their ideas with the use namely of biomimetic principles.
In this context such design principles are proposed in three main directions.

2.1. Michael Pawlyn – a British architect who "has lectured internationally on biomimicry and innovative approaches to environmental sustainability".[2] He was part of the principal team of architects that conceived and designed The Eden Project .

[1] *Lebedev*, Yuri. Архитектурная бионика, [Architekturnaia bionika] Стройиздат [Stroiizdat], 1990 .

[2] exploration-architecture.com/studio/team, 06. 2017

The Eden Project, Nicholas Grimshaw[3]

The main anchor points of his sustainability principles are **radical resource and energy efficiency/savings, closed loop model of using resources – "mimicking an ecosystem" and alternative energy sources (like solar economy).** He also wrote, that "Biomimicry doesn't necessarily mean that all the materials you use have to be biological - it's about applying biological principles to issues such as resource efficiency, cyclical use, etc." [4] So, he is talking about mimicking an ecosystem, and its mature relationships (symbiotic ones), by the use of mainly technology, **the next step will be even not only mimicking, but recreating an ecosystem or developing one.**

Therefore, the natural materials are not a key point but can be very well incorporated and update the biomimicry-based notion for closed loop model and material and energy efficiency. (In one of his talks, he also mentions the usage of calcium carbonate and sodium chloride for light weight building blocks.)

2.2. Another architect, speaking about "nature inspired architecture" is Ken Yeang.

He develops concepts of eco-architecture – that is "alive" as a "living system" (organism), **"analogue to a living constructed ecosystem" – "ecomimesis" – but also even a human-built ecosystem**. This means to "balance inorganic mass with organic mass"[5], into the building itself. He wrote in his dissertation[6] : "...to be fully effective, these technologies need to be thoroughly integrated into the building fabric; they will also be influenced by the physical and climatic conditions of the site".

Solaris, Singapore Science Center [7]

The nature of the problem is therefore site specific. There will never be a standard "one size fits all solution." In his bioclimatic concept he aims the buildings to correspond and optimize the ambient conditions of its surroundings and introduces **vegetation and landscaping into the building itself**, in order to balance "the organic mass with the inorganic mass" of the human built environment.

[3] image - wikipedia.org, 06. 2017

[4] www.ted.com/talks/michael_pawlyn_using_nature_s_genius_in_architecture/discussion, 09. 2017.

[5] „Reintroduction of organic mass to an urban locality to encounter balance inorganic nature of the site" - *Yeang*, Ken, *Richards*, Ivor. Eco Skyscrapers . Images Publishing, 2007

[6] *Yeang*, Ken. "Designing With Nature: The Ecological Basis for Architectural Design". Mcgraw-Hill; y First printing edition, April 5, 1995.

[7] image - www.greenroofs.com, 06. 2017

Yet he doesn't focus on the use of other kinds of natural, or "living" materials (although a selection of materials, based on ecological and "passive" principles is considered advisable). His ecosystematic approach is searched in the balance between biotic and abiotic, as well as between building performance, climate and location (cultural) specifics, also in the possibility for variability, flexibility and adaptation of the structure to the surroundings.

Both architects suggest that buildings (or urban habitats) could be examined as ecosystems, in which animate and inanimate elements interact together. Thus, **symbiotic relations** could be found or even designed within the integration of "synthetic" and "natural" building parts and within the relationship between human, environment and architecture (design and microclimate).

2.3 The third sustainability related theory, that's being introduced to the combined (biomimetic) model is the "Baubiologie". [8]

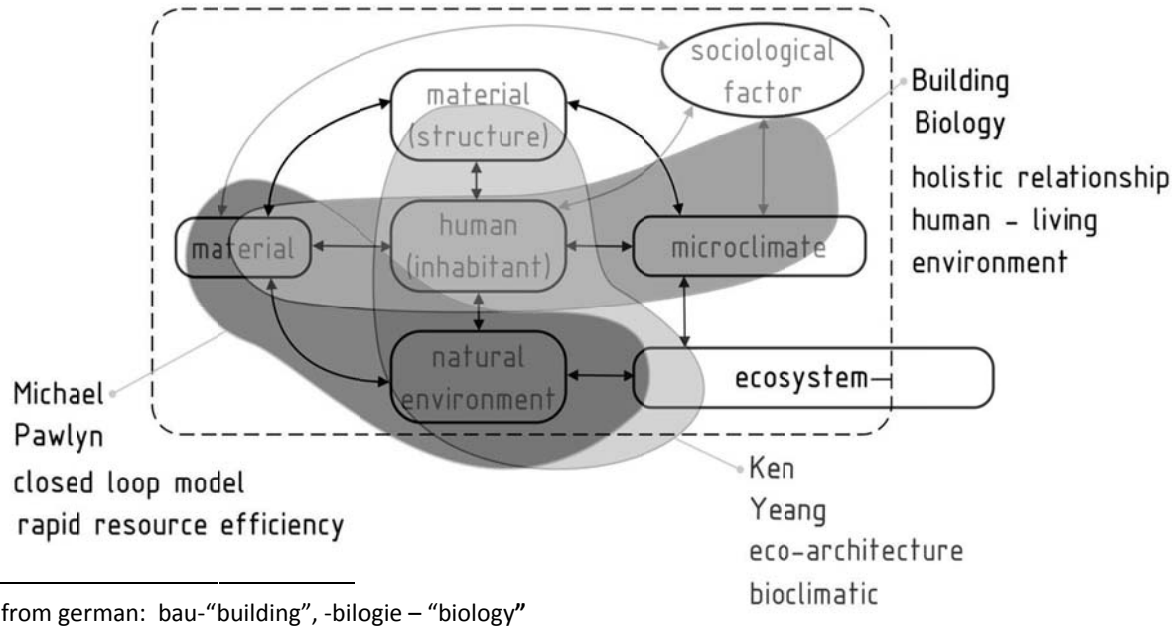
The Building biology studies the holistic relationship between humans and their living and work environments. The building biologists define the house as the "third skin" of the human, and so the home is looked upon as a "living organism", in conjunction with its residents and how the created environment might affect their health or emotions.

Regarding both, materials used and processes and conditions control in the house, it is being strived for as natural as possible principle implementation. (some of the 25 principles of the building biology are related to: *regional materials, non-toxic and healthy living environment, naturally controlled humidity and temperature, energy efficiency, minimized environmental imprint, harmonic measures and proportions, context-related design, etc.*)[9]

So here the focus definitely is on the usage of natural materials and the microclimate created, in comparison to the other two theories, but doesn't include the ecological and sociological aspects of the ecosystem-related approach of the others.

The combination of all this innovative for their time sustainability notions and criteria gives this picture[10] of complex relationships, that could be analyzed in both directions, again in a "closed loop".

- material – material
- material – human (inhabitant) → microclimate
- material – environment → ecosystem



[8] from german: bau-"building", -bilogie – "biology"

[9] www.baubiologie.de , 06.2017

[10] scheme – N.Tsekova

In this unified model of the concepts, the analysis of the biomimetic principles in sustainable architecture can be focused namely on this more complex relation between material-human-context or **how this could be analyzed as an actual symbiotic model** and **how do natural materials fit in that ecosystem scheme, relations and behavior.**

Natural materials as clay, straw, wood, etc. were used even in early human dwellings, that resembled to bird nests, or other animal-made structures like those of beavers, termites , etc. In those examples, the usage of natural materials in such ways could be considered at first as a biomimetic characteristic only on a formalistic level. But by further analysis we could conclude more important biomimetic features – the functional usage of materials, and even more, the validity of the already mentioned "sustainable principles" like **local materials, context consideration and correlation** – which is normally inherent for the natural mechanisms (if not obligatory). **So, the natural, environmentally-friendly building materials are already considered sustainable, because of their local and often more ecological characteristics, but still in this combined model, they also could be regarded from biomimetic point of view.** They could be explored as a part of the implementation of the already mentioned bionic principles such as *aiming the demand for lowering the production of waste materials, the resource and energy use, closed loop model,* as well as *more adequate relation and behaviour of the architecture to the surrounding environment and conditions*. The application of those materials is inspired both from traditional building techniques and from biomimetic ideas.

Thus, in this particular model combination are important not only the "participants", but also the type of relations between them. It is being searched for a biomimetic, non-linear system model, also the "symbiosis" in those connections. **Therefore, I will propose a criterion for symbiosis in architecture for its further investigation.**

III. Symbiosis criteria and levels of relation

The symbiosis as a term in architecture, but in the more philosophical and sociological sense, is used even from Kisho Kurokava in relation to the metabolists movement[11]. He writes also about "co-operating while competing", "the age of the machine vs. the age of life (21st century)"- universalization vs. individualization, plurality, metabolism, metamorphosis – **"the rising interest in the environment and the new importance given to ecology"**. His words could be connected with the sustainable requirement for local context consideration, regional materials, etc., but also "hybrid architecture, in which elements of different cultures exist in symbiosis, an architecture that exists **in symbiosis with the environment, through the symbiosis of tradition and the most advanced technology."** Whereas, in pure biological sense, the dictionary definitions of the word "symbiosis" goes like this: ***"the living together in more or less intimate association or close union of two dissimilar organisms."***[12]

lichen;
clown fish and anemones
[13]

[11] *Kurokava,* Kisho. Philosophy of Symbiosis. Great Britain: Academy Editions, 1994

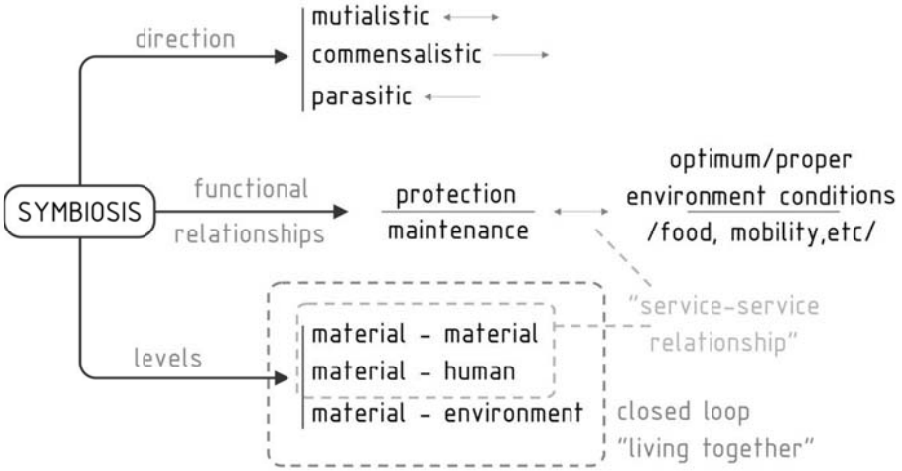
[12] Merriam Webster Dictionary 2017

[13] images: wikimedia.org; www.pinterest.co.uk; 06.2017

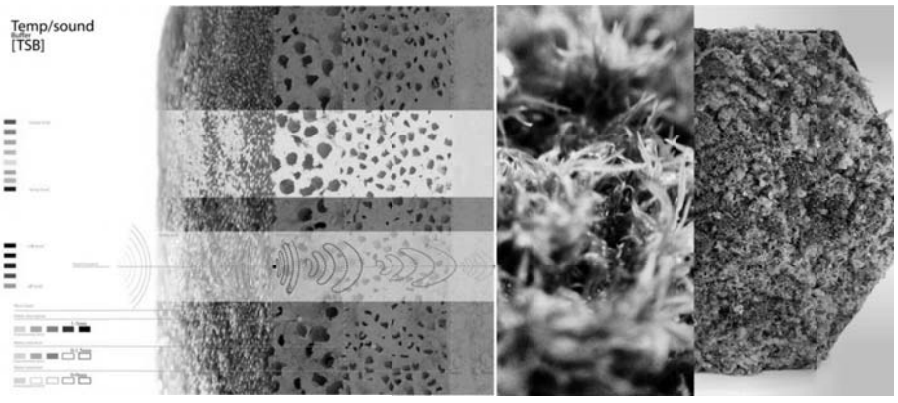
As we go through different well-known examples of symbiosis in nature, *such as lichen, clown fish and anemones, root nodules, goby fish and shrimp, anemone and hermit crab etc.*, we could analyze the types of classification of symbiotic relationships. At the beginning there was an argument among scientists that only mutualism ("reciprocal altruism") is a symbiotic relation. Later they accepted the "de Bary"-definition, that relates to "all kinds of interactions", for more correct.[14]

Thus, the main observed interactions (this is regarding the direction) are mutualistic, commensalistic and parasitic. There are also numerous of other classification types for biological symbiosis – for example, it could be obligatory (entire dependence between the symbionts) or facultative (optional), another known way of classification is by physical interaction – *endo- and ecto(/exo)symbiosis.* But if we go out of the biological frame of definition and classification and analyze the functionality of the relationships, the main type we will find is **providing of protection** or **providing of maintenance in exchange for securing optimum/proper environment living conditions (food, mobility etc.). All those common types for classification can be correlated to the architectural and design context. And also, the search for symbiotic relation could be made on the different levels of interaction[15]:**

- material – material (structure);
- material – living conditions (human/ inhabitant relations);
- material – (natural) environment (in greater scale – city scale - ecosystem);



On each level similar types of classification can be applied – for example, considering the physical interaction factor, on the material-material level, *ectosymbiosis* could be the relation in a layered composite structure, and *endosimbiosys* could be a composite material.



Bioceramics - a studio experiment, developed at IAAC, main author Iker Luna [16]

Considering the latter classification, this is a symbiotic relation on material-material level

[14] *Martin*, Bradford D. *Schwab*, Ernest (2013), "Current usage of symbiosis and associated terminology", International Journal of Biology, 5 (1): 32–45

[15] scheme – N.Tsekova

[16] iaac.net/research-projects/self-sufficiency/bio-ceramic-system/ , 06.2017

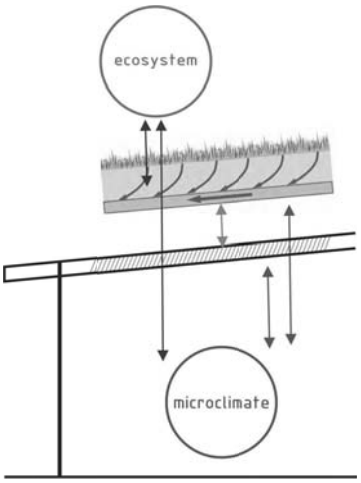
The service-service or service-resource relationships could also be correlated with examples from the levels material-material, material-human. But at this point arises the question: **Is there any difference between symbiotic relation and composite material?** From the point of view of the already mentioned definitions and sustainability models, regarding architecture as an ecosystem model, the symbiosis could be viewed upon from a larger scale, connected with the simple, but very descriptive phrase "the living together". Such connection between material – human – environment context, points to more complex relationships, that concern **not only improvement of certain qualities, but also ecological and sociological factors on ecosystem level.**

Thus, the symbiotic characteristic of a material must be considered and evaluated holistically and complex on all levels.

IV. Approbation of models and criteria: examples and multiple level analysis of the natural materials

Here is one example of green roof system's behaviour, regarding symbiotics and the presented combined model.

1. On material-material (M-M) level : Protects the construction from unsuitable atmospheric conditions (more resilient than hydro insulation);
2. On material – human (inhabitant) (M-H) level : Insulation (thermal, sound), thermal mass function, building microclimate relation;
3. On material – environment (ecosystem) (M-E) level: bioclimatic influence – humidity control, air quality control, alleviates urban heat island effects;[17] biodiversity influence - local vegetation, etc.;



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Let us follow and explore the same model links - M-M, M-H and M-E - in the natural materials as straw, clay and mycelium.

- **Straw – straw bales as a construction (load-bearing), insulation ("infill") material or straw in combination with other natural materials.**
  1. M-M level: maximal efficiency - when combined with other natural materials (lime, clay, wood, etc.); structural stability; material protection;
  2. M-H level : non-toxic, "breathing material" – healthier microclimate; sound and thermal insulation; "virtual" thermal mass effect;
  3. M-E level : negative CO2-imprint; non-toxic production technology, energy use efficiency; use of an disposable product (closed loop model); social impact - local work force, health influence;

[17] "The Benefits and Challenges of Green Roofs on Public and Commercial Buildings" , United States, GNA, 2011

[18] Image - gogreencyclopedia.blogspot.bg, 06. 2017 ; scheme – N.Tsekova

There is a rising tendency for using natural materials in architecture – some of them are inspired from old traditional techniques, some are new or even experimental.
With straw, there are also revived traditional and new modern techniques for building with the material [19]

- Some Examples:

"Nebraska type" (USA) of building with straw bales [20]

Regional example - neolithic restoration - straw in combination with clay, wood and as a roof material[21]

Sieben Linden - Ökodorf, Germany arch. Dirk Scharmer [22]

- **Clay – independently (walls of rammed earth clay), in combinations (with straw, wood, etc.) or as finishing (plaster).**

1. M-M level: maximal efficiency - when combined with other natural materials; structural stability (combined with wood/wooden construction); material protection (combined with straw);
2. M-H level : non-toxic, "breathing material" - healthier microclimate, sound insulation, thermal mass function; humidity control;
3. M-E level : negative CO2-imprint; energy use efficiency; affordable local material; recyclable material; social impact - local work force, short production cycle, health influence, sense for maintaining the ecosystem;

[19] www.asem-bg.org , 06. 2017
[20] naturalmaterials.wordpress.com, 06.2017
[21] *Georgiev,* Georgi. Строителство с естествени материали. Традиционни практики и съвременно приложение. [Stroitelstvo s estestveni materiali. Traditsionni praktiki i savremenno prilozhenie], 2015
[22] siedlungen.eu, 06.2017

With clay, there are also a lot of different techniques – traditional, as well as re-emergency and new applications of old techniques - cob, adobe, cordwood, wattle-and-daub, “light clay”, “earth bags”-construction, “rammed earth” and compressed earth blocks, etc. [23]

- Some Examples:

Characteristic for the Balkan regional architecture is the use of adobe.[24] [25]

cob house(clay,straw), Banya village, Bulgaria , BUDA Architects, Kirilov & Shekerov. [26]

Chapel of Reconciliation (rammed earth)
Part of the Berlin Wall Memorial.
Rudolf Reitermann and Peter Sassenroth, 2000

The chapel consists of a monumental rammed-earth core structure flanked with a translucent facade of wooden louvers.[27]

[23] *Georgiev,* Georgi. Строителство с естествени материали. Традиционни практики и съвременно приложение. [Stroitelstvo s estestveni materiali. Traditsionni praktiki i savremenno prilozhenie], 2015
Valchanova, Varvara. “Земно строителство. Материали, техники, поддръжка.” [Zemno stroitelstvo. Materilai, techniki, poddrazhka.] Пловдив: Издателство „Сдружение Раховица“, 2013

[24] Adobe (a mixture of clay, organic fibers’(straw), sand) – it’s used for sun-dried bricks or in a combination with “woven” wall structures. (Normally those walls are also finished with lime or clay plaster), *strawclaywood.com*

[25] images – left – personal archive –N.Tsekova- (Chavdar, Bulgaria), right – Kovatschevitsa, Bulgaria - patepis.com

[26] www.capital.bg/biznes/predpriemach/2011/06/24/1112175_kushtata_na_minaloto , 06. 2017

[27] inhabitat.com, 06.2017

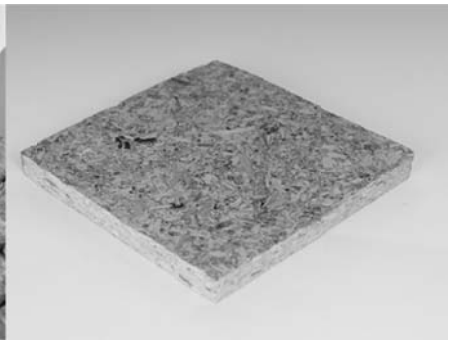
- **Mycelium – as construction material (compressed bricks/board), as insulation - thermal, acoustic, as experimental biocomposite materials**

1. M-M level: maximal efficiency - when combined with other natural materials, self-bonding structure; material protection (water/**fire**/mold-resistant);
2. M-H level : non-toxic, "alive material", sound and thermal insulation (very efficient in storing energy);
3. M-E level : negative CO2-imprint, energy use efficiency, adaptability, recyclable(compostable), usage of waste material (sawdust), improve air quality, alleviate urban heat island effects.

According to Meriam-Webster Dictionary mycelium is "the mass of interwoven filamentous hyphae that forms especially the vegetative portion of the thallus of a fungus and is often submerged in another body (as of soil or organic matter or the tissues of a host)", meaning these are the rootlike fibers of fungi, that expand under the surface of the soil into a dense network for growing mushrooms.
Mycologist Philip Ross started experimenting with mycelium in his art installations, combining mushroom tissue with different "body-structural materials", like sawdust, growing it into different form molds. Later he realized the potential of the mycelium-formed building blocks also for the field of architecture and design. In comparison to the other listed natural materials, this one is still experimental and there is no traditional usage of the material. Here are some examples:

Hy-Fi Mushroom Tower pavilion at the MoMA Ps1. David Benjamin , "The Living", Ecovative Mycelium Brick technology [30]

Philip Ross, MycoWorks[28]



Ecovative – environmentally friendly insulation material that outperforms traditional fiberglass.[29]

Joe Dahmen and Amber Frid-Jimenez , moulded oyster mushroom spores and alder sawdust into a bench[31]

[28] buildabroad.org - *Mycoworks- "*The creative team of engineers, designers and scientists are experimenting with transforming agricultural waste into durable and robust bio-materials, using help from mushrooms.", image - inhabitat.com, 06. 2017
[29] greenbuildingelements.com, 06. 2017
[30] greenbuildingelements.com : "Building on the pioneering work of Paul Stamets, an American mycologist (a fungi botanist), Eben Bayer and Gavin McIntyre, two mechanical engineers, …, founded a company called Ecovative to produce building products from mycelium. The company name is a composite of "ecological" and "inniovative."
[31] phys.org, 06.2017

V. Conclusion

As a conclusion could be said, that again from biomimetical point of view, the interconnection of all these aspects and models of sustainability issues is very important part of their continuous development and evaluation properties for architectural materials. Thus, the search for symbiotic relation, for ecosystem model and its connection with the human factor, combined with the corresponding analysis of the aspects will presumably help the optimization, efficiency, adaptability, and desired influence and performance of the sustainable architecture, working as a whole system.

In this trace of thoughts, also other traditional natural materials as bamboo, metal, stone or experimental as the mycelium and some complex composite/symbiotic materials (like the bioceramics), could be analyzed and evaluated in the frame of the symbiotic criteria.

Bibliography:

Knippers, Jan. *Nickel,* Klaus G. *Speck,* Thomas. "Biomimetic Research for Architecture and Building Construction. Biological Design and Integrative Structures." Springer International Publishing, Switzerland, 2016

Yeang, Ken, *Richards,* Ivor. Eco Skyscrapers . Images Publishing, 2007

Yeang, Ken. "Designing With Nature: The Ecological Basis for Architectural Design". Mcgraw-Hill; y First printing edition, April 5, 1995.

Pawlyn, Michael. "Biomimicry in Architecture", Riba Publishing, 2011

Kurokava, Kisho. Philosophy of Symbiosis. Great Britain: Academy Editions, 1994

Martin, Bradford D. Schwab, Ernest (2013), "Current usage of symbiosis and associated terminology", International Journal of Biology, 5 (1): 32–45

Georgiev, Georgi. Строителство с естествени материали. Традиционни практики и съвременно приложение. [Stroitelstvo s estestveni materiali. Traditsionni praktiki i savremenno prilozhenie], 2015

Valchanova, Varvara. "Земно строителство. Материали, техники, поддръжка." [Zemno stroitelstvo. Materilai, techniki, poddrazhka.] Пловдив: Издателство „Сдружение Раховица", 2013

Lebedev,Yuri. Архитектурная бионика [Architekturnaia bionika], Стройиздат [Stroiizdat], 1990

Alexander, C. A. *Pattern Language*, Towns, Buildings, Construction, [1968], Center for Envirinmental Structure studies, OUP USA, 1978.

Hillier B., J. Hanson. *The Social Logic of Space*, Cambridge University Press,1984

"The Benefits and Challenges of Green Roofs on Public and Commercial Buildings", United States, GNA, 2011

"25 Principles of Building Biology", Institut für Baubiologie + Nachhaltigkeit IBN25, Germany